

THE PROBLEM OF THE MARTIAN YELLOW CLOUDS

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The first extensive meteorological investigations of other planets were undertaken starting just about 15 years ago at Lowell Observatory. The Project for the Study of Planetary Atmospheres was sponsored at first by the U.S. Weather Bureau, through its Scientific Services Division, which was then directed by Dr. Harry Wexler. Perhaps only those comparatively few meteorologists who participated in these early studies can fully appreciate the keen foresight and remarkable scientific intuition that motivated Wexler's active encouragement of this project in days when research funds even for the conventional tasks were so difficult to come by. The following remarks on the problem of the Martian yellow clouds are offered in part as a reminder of the continuing validity of one of Wexler's favorite theses, that meteorologists can with profit study the atmospheres of other planets in order to improve their understanding of the behavior of the earth's atmosphere.

Observers of the planet Mars classify visual and photographic obscurations of that planet's surface features, somewhat arbitrarily, as "yellow clouds," "white clouds," and "blue haze." These names refer in part to actual visual appearance, in that the yellow clouds usually have an ochre tinge; but the allusion is also to the photographic appearance of the phenomena. If Mars is photographed in the light transmitted through a blue filter, surface markings are obscured and an overall hazy appearance results. This "blue haze" is certainly an atmospheric phenomenon, probably occurring at a considerable elevation; but it is not yet entirely certain what its exact nature is. The "yellow clouds," on the other hand, are usually isolated and more or less clearly delimited obscurations of comparatively small areas of the Martian disk and can be detected visually or in photographs made with yellow or red filters. The "white clouds" are also isolated features, appearing strongest in blue or violet light, and are rarely detected in the red or infrared.

Because of the very small quantity of water vapor that is present on Mars, the white clouds, which are probably aqueous, are not widespread. They tend to be confined to the sunrise and sunset edges of the planet, particularly during the fall and winter seasons, and to certain presumably elevated regions, such as Hellas. These clouds, or frost deposits, normally exhibit little or no motion and have been compared to low-lying fogs on the earth.

Rare as are the white clouds, the yellow clouds are even more uncommon; but, since they often persist for several days and occasionally display movement, they are of particular meteorological interest. Because of their color and certain other optical properties, it has been concluded that the Martian yellow clouds are composed primarily of dust. The facts that the yellow clouds are most frequent during perihelic oppositions (that is, when distance Mars-sun is least), and that they seem to show some preference for low latitudes, have suggested an interpretation as low-level convective phenomena. On the other hand, their tops must occasionally reach considerable elevations, perhaps as great as 50 km. or more, since they have frequently been detected visually, as detached projections on the Martian terminator. In other words, their tops have on occasion appeared illuminated in the light of the setting sun, permitting a rough, quantitative estimate of elevation to be made.

Hess [1] studied 18 Martian yellow cloud motion observations, and was able to draw a tentative Martian streamline map from these; see figure 1. Although it is considered to be far more provocative than demonstrative, the map implies a circulation pattern that is quite similar to terrestrial patterns. The yellow cloud motion data used by Hess were primarily those obtained at Lowell Observatory during the oppositions of 1894 and 1896, and refer to the southern hemisphere summer season. These clouds were observed as limb and terminator projections, and hence must have, in general, extended to fairly great elevations. It is interesting that most of these yellow clouds occurred at fairly high latitudes.

Yellow clouds that appear as surface obscurations in photographic or visual observations have been discussed by many observers of Mars. In particular Slipher [2] has recently published an extensive summary, including many photographs and descriptions. Based on this information, and on de Vaucouleurs' [3] well-known list of examples, the writer has tabulated a number of yellow cloud motions, including: the direction and average speed where available, the region and latitude of origin on Mars, the terrestrial year, and the equivalent Martian southern hemisphere dates of the observations. See table 1. (Because the image of Mars is inverted in a

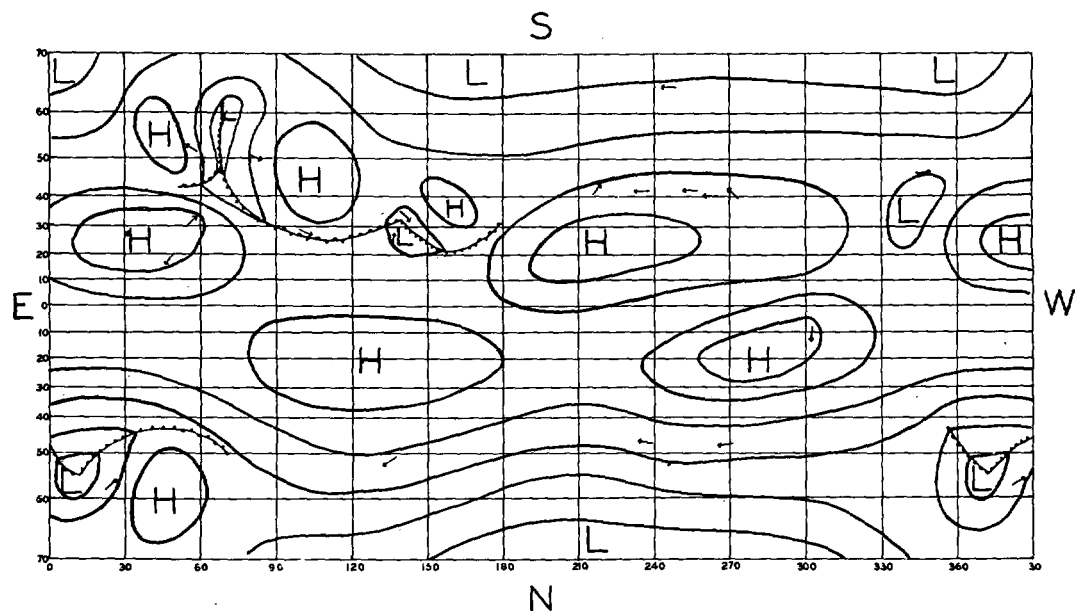


FIGURE 1.—Streamline map of Mars for the southern hemisphere summer season, after Hess [1]. The arrows indicate observed yellow cloud motions.

telescope, and to facilitate discussions, it is conventional to consider an equivalent Martian calendar whose southern hemisphere vernal equinox occurs on March 21.)

This listing provides an interesting supplement to Hess's collection. In the first place, these clouds represent all seasons of the Martian year except fall. On the other hand, all but two of the clouds originated equatorward of latitude $\pm 25^\circ$; i.e., in tropical latitudes (the inclination of Mars' equator to its orbital plane is 25°). The duration of these yellow clouds, or dust storms, is short, usually one to three days. This is in contrast to terrestrial mid-latitude storms which may last for a week or more. Most of the dust storms are first observed over or quite near low-latitude desert areas. Comparison with Martian seasonal surface isotherm maps (Gifford [4]) reveals that all the areas of origin of the yellow clouds of table 1 are characterized by average temperatures equal to or greater than 280°A . This corresponds, in each case, to a region

of maximum temperature on the planet. Perhaps the most striking fact to emerge from table 1 is the tendency of these dust storms to move *equatorward*. This is in contrast with terrestrial cyclonic storms, all of which ultimately exhibit a marked poleward movement.

In view of the known dryness of the Martian atmosphere, the desert location of most of the yellow clouds of table 1 and their occurrence in regions of comparatively high surface temperature certainly tend to confirm the hypothesis that they are dust clouds, probably initiated by thermal convection. Their generally equatorward drift seems to imply that they are low-level phenomena, possibly steered by the tropical portion of a symmetric circulation cell.

There does not seem to be any marked tendency for these dust storms to persist, or to develop into extra-tropical storms. Considered as perturbations on some steady-state circulation regime, they appear to be damped out fairly rapidly. The dust storms are, moreover, fairly small, of the order of several hundred to 1000 km. in horizontal extent. Mintz [5] has calculated that the "dominant wave number" on Mars (see Thompson [6] for a detailed discussion of this concept) equals 3, and so it seems that the dust storms are much too small to be related to large-scale baroclinic instability.

It is clear even from the foregoing brief discussion that the Martian "yellow clouds" are evidently an interesting and fairly complex group of phenomena having at least two fairly clearly discernible component parts. Many yellow clouds appear to originate in low-latitude desert areas, and to persist for only short periods, during which they usually drift equatorward and are confined to low elevations, perhaps a maximum of 5 to 10 km. Others,

TABLE 1.—Moving Martian yellow clouds

Year of observation	Equivalent Martian southern hemisphere date	Region	Latitude first observed	Average direction and speed (m.p.h.) of motion*
1937	Feb. 10-12	Syrtis	20°N.	→6
1937	Feb. 22-24	Candor	0°	↘5
1922	Mar. 28-30	Margaritifer	15°S.	↘11
1924	May 14-15	Isidis	15°N.	↓23
1958	July 29-31	Isidis	15°N.	↘22-27
1911	Aug. 2-7	Libya	10°N.	↘10-15
1943	Aug. 3-5	Libya	0°	↘22-30
1941	Aug. 1-10	Libya	20°N.	↘~20

*The net direction of motion has been estimated by the writer from the published descriptions of the first and last cloud positions that were observed in each case.

such as most of those studied by Hess, are observed at comparatively high latitudes and extend to much greater elevations above Mars' surface. The latter exhibit motions that may possibly have analogies with terrestrial circulation patterns. The former, that is the low-level, low-altitude yellow clouds of table 1, do not appear to have any obvious terrestrial analogy; and their explanation, particularly their marked equatorward drift, would seem to pose an interesting problem for dynamic meteorology.

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